

Adaptive Sampling During AOSN-II

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LONG-TERM GOALS

The main purpose of the Autonomous Ocean Sampling Network (AOSN) is to provide an integrated framework in which data collected from underwater robotic vehicles are utilized in numerical ocean models, in order to improve predictive skill of physical, chemical and biological aspects of the coastal ocean. The research documented in this report is aimed at developing an objective strategy to identify locations for observational data to be collected, to improve 0-3 day ocean model forecasts. In the future, a trustworthy “adaptive sampling” or “targeting” strategy may be used operationally to coordinate deployments of multiple mobile observational platforms on a daily basis.

OBJECTIVES

The primary objectives of the research effort described herein are

- (i) To develop reliable ensembles of numerical ocean model forecasts.
- (ii) To understand the response of the ocean to changes in atmospheric wind stress.
- (iii) To test the efficacy of the Ensemble Transform Kalman Filter (ETKF) targeting strategy.
- (iv) To compare the ETKF versus Error Subspace Statistical Estimation (ESSE)

APPROACH

The focus for the above objectives has been the AOSN-II Field Trial in Monterey Bay, which took place throughout August 2003. The primary collaborators on this project are (role in parentheses):

- Dr Yi Chao, NASA Jet Propulsion Laboratory (JPL). (Coordination of Regional Ocean Modeling System – ROMS – modeling project during AOSN-II)
- Dr Zhijin Li, JPL/Raytheon. (ROMS modeling and data assimilation during AOSN-II)
- Dr Jei-Kook Choi, JPL/Raytheon. (ROMS modeling and data preparation during AOSN-II)
- Dr Craig H. Bishop, NRL Monterey. (Atmospheric forcing, targeted observations)
- Dr Pierre F. J. Lermusiaux, Harvard University. (Inter-comparison of targeted observing strategies)

The initial priority of the funded research was to develop a robust software infrastructure on the SGI supercomputers at JPL, to enable ensembles of ROMS model forecasts to be run every night during AOSN-II. The development of a reliable technique to perturb each ensemble member is a major

objective of our research. So far, two perturbation methods have been constructed. The first is aimed at capturing uncertainty in the ROMS initial conditions. During AOSN-II, the breeding technique (Toth and Kalnay 1993) was used, and this will be superseded by the technique of Wang and Bishop (2003) in retrospective and future ensemble runs. The second ensemble perturbation method aims to capture uncertainty in the atmospheric wind stress fields at the ocean surface. These fields are prescribed to ROMS via the COAMPS model, issued in real-time at 3-km resolution by NRL Monterey. A new experimental technique based on autoregressive functions has been developed to perturb the evolving COAMPS atmospheric wind stress forecasts out to three days.

After the ensemble forecasts have been post-processed at JPL, an ensemble-based targeting strategy is then used to predict optimal locations for mobile observing platforms to be deployed. The Ensemble Transform Kalman Filter (ETKF, Bishop et al. 2001), which has been used in aircraft reconnaissance for the past 5 winters (Majumdar et al. 2002) is being modified for use with the ROMS ensembles. The ETKF rapidly produces “summary maps” of the predicted reduction in analysis/forecast error variance, for any hypothetical future observations of physical variables. A theoretical comparison is under way between the ETKF and a related strategy, Error Subspace Statistical Estimation (ESSE, Lermusiaux and Robinson 1999), which is also being used for adaptive sampling during AOSN.

Two key studies will be conducted in FY04 on the JPL supercomputers:

First, the ROMS ensembles will be re-run for the entire AOSN-II period in August 2003, based on the retrospective ROMS model analyses that will be prepared by the JPL group, using quality-controlled data collected during AOSN-II. Larger ensembles (>20 members) will be run than was feasible during AOSN-II (8 members). The ensemble perturbation method for wind stresses will be evaluated, and the sensitivity of the ROMS ocean model state prediction to the atmospheric forcing will be studied. This is a key research question, since the changes in the ocean state in and around Monterey Bay (upwelling and relaxation periods) were found to be closely associated with changes in the wind field.

Second, the ETKF targeting strategy will be run on the new ensembles, for a large number of ROMS model analysis and forecast cases. An understanding of why the ETKF identifies specific regions for targeting will be developed via consideration of the physical processes taking place, and the performance of the ETKF will also be evaluated. Using parallel integrations of the ROMS model, with and without specific datasets in the assimilation, the impact of those datasets will be calculated. The ETKF’s ability to predict this impact, via a quantity entitled “signal variance” will be deduced, using the techniques of Majumdar et al. (2001, 2002) and Bishop et al. (2003).

WORK COMPLETED

The project was initiated in April 2003. The software development and testing was performed between April and August, prior to and during the AOSN-II Field Trial. Dr Majumdar spent the entire month of August working in the “AOSN Control Room” at the Monterey Bay Aquarium Research Institute. The following components of the ensembles and adaptive sampling framework have been completed:

- (i) Ensembles of 3-km COAMPS model forecasts (Fig.1a)
- (ii) Ensembles of initial conditions for the ROMS model
- (iii) Combining (i) and (ii), 3-day ensembles of ROMS model forecasts were produced. (Fig.1b)
- (iv) Using these ensembles, the ETKF strategy has been developed. “Summary maps” of predicted reduction in forecast error variance have been produced (Fig.2)

These components were run in real-time whenever possible during AOSN-II, and the work in progress was presented to the AOSN-II community at MBARI throughout the experiment.

RESULTS

Since the project is in its early stages, there are not yet any substantial scientific results. As described above, the computational framework has now been developed for key ocean modeling and adaptive sampling studies to be performed. The main qualitative results based on the ensembles and ETKF products run during AOSN-II have been the following:

- (i) The ROMS model forecasts show considerable sensitivity to changes in the atmospheric forcing field (see Fig.1 for an example from AOSN-II)
- (ii) The ETKF adaptive sampling summary maps have shown promise in identifying potential paths for underwater gliders and AUVs to pursue (see Fig.2 for an example from AOSN-II)

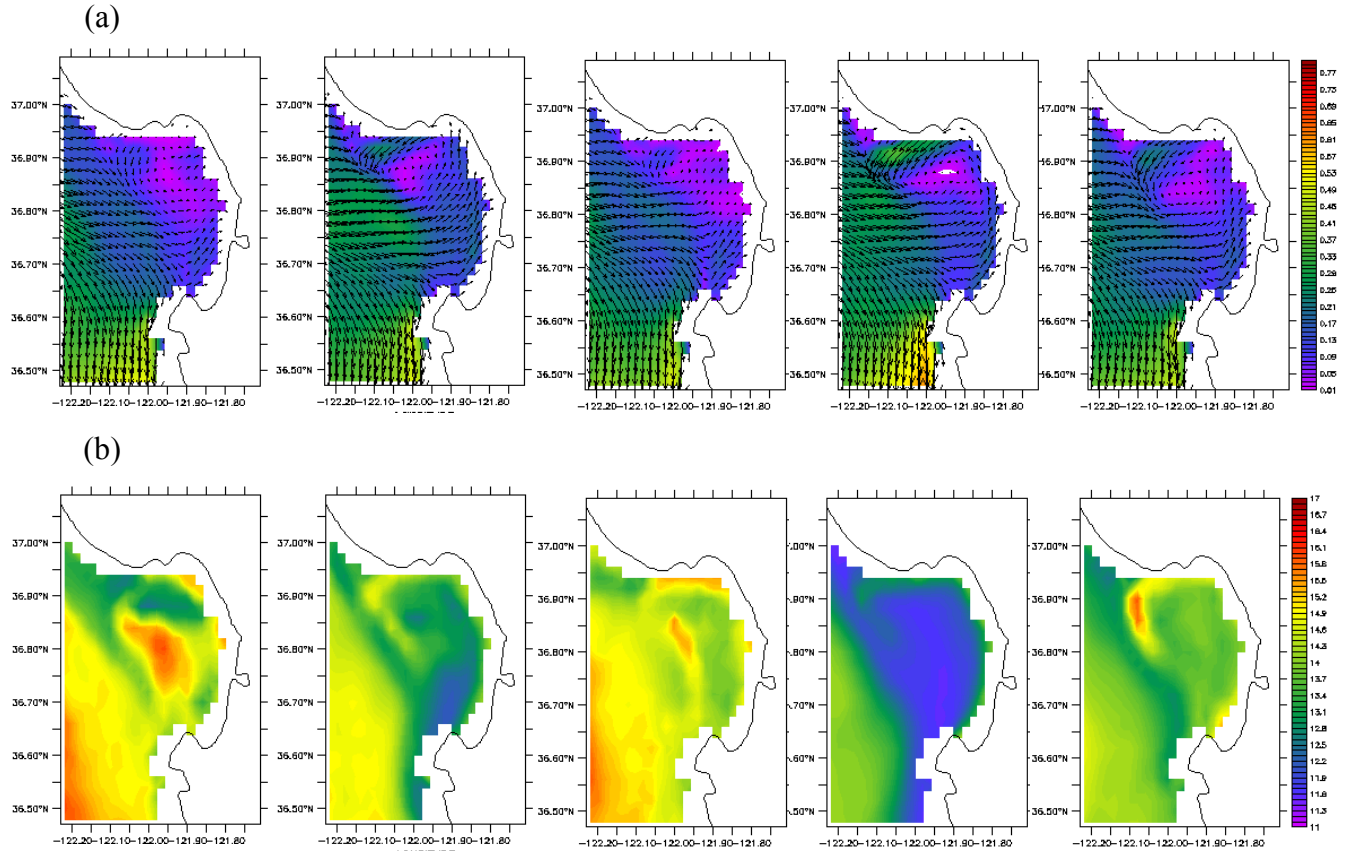


Figure 1. (a) Five ensemble members of the COAMPS 3-day surface wind stress forecast, valid on September 3, 2003. Vector gives direction of wind stress, shading gives magnitude. (b) Five 3-day ROMS ocean model SST forecasts, each forced by the wind stress field in the panel directly above.

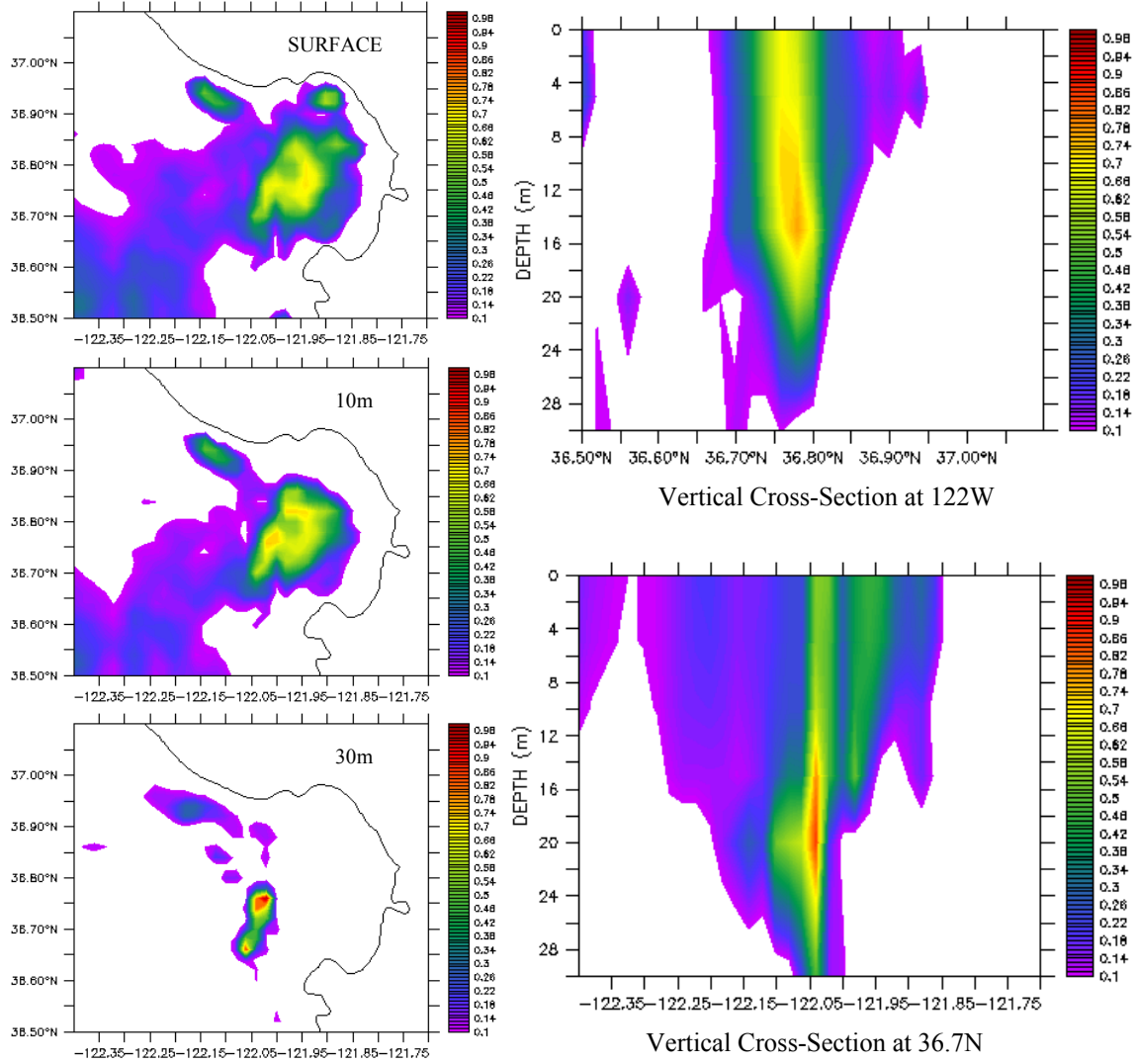


Figure 2. *Horizontal and vertical cross-sections of ETKF “summary maps” of reduction in forecast error variance, as a function of observation location (units are normalized). An 8-member ROMS ensemble initialized on August 31 2003 is used. The maps correspond to AOSN-II adaptive sampling on September 1, with the aim being to improve a 24-hour ROMS model forecast of surface currents in Monterey Bay valid on September 2. The summary map suggests that extra observations of the ocean currents ought to be taken in the mouth of Monterey Bay between the surface and 15m (yellow shading), and in a more concentrated region near 122W, 36.75N, to a depth of 30m. Based on ETKF maps and cross-sections like these, paths for underwater observing instruments can be rapidly designed on a regular basis, depending on the flow of the day, and the physical feature of interest that needs to be better modeled.*

IMPACT/APPLICATIONS

One key scientific issue to arise from this study is the uncertainty of how the ocean responds to the atmospheric wind stress (and other fields, such as heat fluxes). Over the next year, a detailed study will be performed to identify how the ROMS model state in the Monterey Bay region responds to changes in the 3-km resolution COAMPS wind fields. Via this investigation, a clearer understanding of the role

of the winds in driving oceanographic processes such as upwelling and mesoscale circulations (eddies etc) can be accomplished.

A theoretical intercomparison between the ETKF targeting strategy, and the related Error Subspace Statistical Estimation strategy (ESSE, Lermusiaux and Robinson 1999) is being conducted in collaboration with Dr Pierre Lermusiaux. Once a better understanding of the relative strengths and weaknesses of the respective strategies has been achieved, a *modified targeting strategy will be developed* for use in future AOSN experiments and similar projects.

Another key scientific and practical issue is the evaluation of the ability of the targeting strategy to make quantitative predictions of the influence of specific observation sets on model analyses and forecasts. This can now be achieved within the ROMS model framework at JPL without extensive coding. The results from this study will give a measure of the reliability of the targeting strategy in being able to discriminate between good and poor regions (and times) for mobile observational resources (e.g. gliders, AUVs) to be deployed.

RELATED PROJECTS

The ETKF targeting strategy is currently being used operationally for aircraft reconnaissance missions, to improve 1-5 day weather forecasts. The strategy is being extended and tested to be applicable for synoptic surveillance missions in the environment of hurricanes. Dr Majumdar is presently conducting studies (funded by NOAA) to test (i) the reliability of the ETKF in non-linear flow regimes and (ii) how to maximize useful error covariance information, given the necessarily small number of ensemble forecasts. The conclusions drawn from these studies will have a direct impact on the development of adaptive sampling / targeting methods for underwater vehicles such as gliders and AUVs.

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